National Science Foundation – ATLAS Phase II Upgrade

Final Design Review – Panel Report

9/19/2019

The "A Toroidal LHC ApparatuS" (ATLAS) experiment is one of two large general-purpose particle physics detectors built on the Large Hadron Collider (LHC) at CERN in Switzerland and France. ATLAS will learn about the basic forces that have shaped our Universe since the beginning of time and that will determine its fate. ATLAS data enables exploration of extra dimensions of space, unification of fundamental forces, and evidence for dark matter candidates in the Universe. Following on from the discovery of the Higgs boson, data from an upgraded ATLAS detector will allow detailed investigation of Higgs boson properties, and thereby of the origin of mass.

The ATLAS detector began operating in 2008, and there are now plans for a large upgrade of the detector that would come online in 2026. The United States (US) component of the ATLAS upgrade (approximately 17% of the endeavor) is being considered for major new funding by the National Science Foundation (NSF) and Department of Energy (DOE). These agencies support a joint project office developing the US contributions to the ATLAS upgrade, with the NSF components of the upgrade approaching final design review (FDR) status in late 2019. The US is the largest single country in the ATLAS collaboration.

This report is based on a series of talks and documents presented to the FDR Panel in Alexandria, VA on September 11-13, 2019. The important goals of the review were (a) to assess whether the ATLAS collaboration has completed all NSF-mandated pre-construction preparations needed to enable construction to commence in April 2020; and (b) advise NSF as to whether implications of remaining development activities and decision points - planned for the interval between FDR and April 1, 2020 - are reasonably bounded within the ATLAS cost, scope, and schedule estimates, thereby supporting a strong recommendation for construction in April 2020. The FDR panel members are listed in Appendix A, and the formal charge to the review panel is given in Appendix B. This report has three main sections, reflecting the structure of the review, examining: (a) Management, (b) Technical Review and (c) Project Cost/Schedule/Risk areas.

Executive summary

- We believe the project will be ready for the scope of activities proposed for MREFC funding by April 2020 – **we unanimously consider this FDR successfully passed**.
- An excellent science case and exemplary flow down to technical and operating requirements were demonstrated. Reviewing the US elements of the HL-LHC science case was a highlight of the meeting.
- Scope/budget/schedule/risk information has been developed and was explored in detail by the Panel; we found the project definition to be well-structured, comprehensive, detailed and precise.
- Technical and programmatic risks/uncertainties are well-documented, understood, impacts appear understood and reasonably bounded, and careful risk management is underway.
- An experienced and well-prepared team is in place, including significant Phase 1 experience. Effective management of the subsystems by the project office is apparent.
- The ATLAS MREFC team is planning to appropriately leverage the project as an opportunity to educate & broaden participation. Further development of these plans is a priority.
- External risks are visible: CERN schedule, commodity prices etc. – and the project has developed detailed estimates of impacts and developed workarounds/mitigations to address.
- Separation of the pre-MREFC and MREFC tasks (an issue noted at PDR) is now adequately defined and appropriate.
- The work remaining between this review and the start of project (April 2020) includes key activities and important decisions – we encourage the project and NSF to work together closely to monitor the outcomes through the end of the pre-MREFC phase.
- We believe the Construction Readiness Criteria items 1-5 (Completion of Design Development Phase; Project Scope Definition; Project Budget detailed; Project Schedule Integrated; PM/PEP/subaward management in place) have been met by all four technical subsystems.
- Risk Management procedures and positive attitudes/culture are highly-visible and being used effectively by the project.
- Project Office leadership and the interactions with CAMs is effective and provides confidence that the MREFC project will be well managed.

Management Review

1. **Based upon the panel's examination of the project team's technical preparation and pre-construction planning, is the project team ready to undertake MREFC-funded construction in April 2020?**

   We believe the Construction Readiness Criteria items 1-5 (Completion of Design Development Phase; Project Scope Definition; Project Budget detailed; Project Schedule Integrated; PM/PEP/subaward management in place) have been met by all technical subsystems. Detailed technical comments are available later in the report.

2. **Based upon the FDR panel's assessment of the project team's risk planning, advise NSF of the panel's level of confidence that the project team can complete the proposed scope of work within the budget and schedule requested.**

   We have confidence that the project can complete the proposed scope of work within the budget and schedule requested, including the estimated contingency. Detailed risk analysis of the program is underway, and in many cases mitigations and "Plan Bs" are identified. Risk Management procedures and positive attitudes/culture are visible and being used effectively by the project. We believe the risk management criteria have been met by the project's Risk Management Plan. We note that final production of some subsystems awaits the completion of the international ATLAS reviews, allowing only pre-production activities in some cases.

3. **Does the project team have a meritorious plan to leverage NSF's MREFC investment in the high luminosity detector upgrade to achieve broader societal impacts?**

   Given the fact that this is an MREFC project, achieving broader impacts through a focus on supporting the students doing the work has a lot of merit. Although in a relatively early stage of development (compared to the technical definition of the project), planning for these activities is actively underway.

4. **Recommend issues, if any, for special NSF attention during remaining planning activities or during the first year of construction. Advise NSF on the adequacy of plans for financial and technical status reporting, and for oversight of subawardee performance by the awardee.**

   The Panel cannot identify anything in the remaining development phase requiring additional scrutiny.

Specific Charge Items:

1. **The project has achieved the necessary level of technical preparation and readiness to begin construction.**

   Yes.

2. **The project's scientific and technical contributors are credibly expected to accomplish the proposed work scope within the requested budget and schedule duration.**

   Yes.

3. **There is a project management team in place that has the capacity and capability (number of personnel, skill set, effectiveness, quality, organizational structure, division of roles/responsibilities, and processes for assigning work) to initiate and effectively manage the project, including appropriate supervision of subawards, beginning in April 2020 and throughout construction.**

   Yes.

4. **The project has finalized all necessary commitments and partnerships, including definition of project deliverables, performing organizations, and schedules.**

   Yes.

5. **The project has a defined acquisition strategy for purchased items. Designs, specifications and work scope comprising bid packages to industry are in advanced states of maturity and available for NSF review. Bid packages to be released in FY2020 are sufficiently clear and well defined as to be ready for bid.**

   Noting that final procurements will await completion of the ATLAS-level reviews (i.e. the project is initiating pre-Production April 2020), yes.

6. **MOU's and first year SOWs with subawardees are complete. Subaward budgets are well documented, including documentation of overhead rates by subawardee institution.**

   Yes, the appropriate agreements appear to be in place or prepared for the MREFC phase.

7. **Tools and technologies needed to construct the project are available. Industrialization of key technologies needed for construction is complete.**

   Good PM tools and practices are in place and being used effectively. Technologies required for the project appear to be available commercially or have been developed by the project.

8. **Recruitment of key staff and control account managers needed to commence construction of the project is complete.**

   Yes.

9. **The Earned Value Management System is ready to be used during construction and there are plans in place for acceptance by NSF prior to construction award.**

   This system was not reviewed in detail by the FDR panel, but we believe the EVMS is in place and being used effectively by the project.

10. **The project team certifies that:**
    a. **All pre-construction planning topics, including those listed in Section 3 of the NSF Major Facilities Guide3 concerning the Project Execution Plan (PEP), are fully complete and determined to be adequate.**

       Yes

    b. **All pre-construction planning topics required by the MFG (section 2.3) are fully complete and adequate.**

       Yes.

Technical Review

Trigger

The maturity of the designs is appropriate for this stage of the project.

L0 CalorimeterTrigger

Findings: The L0 Calorimeter project consists of building a system to remap fiber optic signals from the detector to be used in the trigger. This is very similar to a similar project successfully completed for the ATLAS Phase 1 upgrade project. The only change is that for HL LHC a different mapping of fibers needs to be implemented.

Comments/Conclusions: This is a straight forward project to complete with little technical risk.

HTT

Findings: The HTT is a custom coprocessor system used to perform track fitting in the ATLAS higher level trigger. The NSF scope includes significant hardware and firmware responsibilities. Since the PDR, the level of engineering effort on the system has been significantly increased. However, much of the firmware will be written by scientific labor and as such is poorly tracked by EVM. The project will use detailed milestones to track the progress of that firmware development. The fabrication of the electronics boards comes late in the MREFC project schedule. Prototype designs should be sent for fabrication in late September or early October, allowing for initial testing of these boards to have been completed before the start of the MREFC. Multi-board tests are scheduled for 2021

Comments/Conclusions: The project is well motivated by a multitude of physics channels. The late fabrication of the hardware is appropriate for a project of this nature. The addition of engineering to the project is very welcome, although, there is a risk (included in the risk register) that it may still not be adequate.

Global Trigger

Findings: The NSF funded scope in the global trigger is devoted to the implementation of firmware for the system. Of particular importance is the development in firmware of many key physics algorithms used to select events in real time for processing in the higher level trigger. Scientific labor will be used to develop the algorithms that will then be implemented in firmware by engineers

Comments/Conclusions: The project appears to be particularly well organized, which is important given the variety of institutions participating in it. The project is very strongly motivated by the physics goals of the project.

a. **Project documentation describes how the construction-ready design is derived from the flow-down of science goals to science requirements then on to technical performance specifications and requirements. The documentation is in a format that enables traceability, is clearly explained, and is aggregated into a dedicated section of the PEP.**

   Yes

b. **All detector functions and requirements are reflected in the Performance Measurement Baseline.**

   Yes

c. **Scope documentation includes modelling of impacts to science goals resulting from detector over- and under-performance.**

   Yes

d. **The project has identified and assessed the impacts on the project resulting from any changes to scope requirements since the Preliminary Design Review (PDR).**

   Yes

e. **Design specifications and drawings are complete and of high quality. Review any changes in technology since the PDR.**

   The design specifications are at an appropriate level of development for the current stage of the project.

   - The L1 Calorimeter work must await the final mapping of the calorimeter fibers.
   - The fabrication of the production HTT system will be appropriately late in the project, and the maturity of the designs is appropriate for this stage of the project. Since the PDR there has been a change to an FPGA that includes more memory. This will more easily allow the implementation of the firmware used in the project, in particular coping with the large number of constants that are used in the algorithms

   The maturity of the Global Trigger firmware designs is appropriate for this stage of the project.

f. **Specialized technologies enabling the scope fabrication are sufficiently mature to begin construction.**

Yes.

g. Technical scope elements of the performance baseline remain consistent with what was approved for advancement to Final Design stage following PDR.

Yes.

h. Work packages and Control Account Managers are assigned for construction work anticipated to begin in FY 2020.

Yes.

Liquid Argon

The pre-MREFC R&D for the LAr system has progressed well. The designs are at the appropriate maturity level and will be ready for the start of MREFC in 2020. The team should continue to retain the backup option of COTS ADC as well as the descope option of reading out only a single gain range until associated risks are retired.

Findings:

- LAr electronics upgrade provides full granularity, full precision readout at 40 MHz bunch crossing frequency, necessary for maintaining a trigger threshold in the HL-LHC era.
- US plays a leading role in the LAr upgrade, with funding from both the NSF and DOE. The NSF scope includes the front-end electronics (WBS 6.4.1), front end board (WBS 6.4.2) and the backend electronics (WBS 6.4.3). DOE is responsible for the preamp/shaper ASIC and the system integration.
- Five iterations of the ADC ASIC with yearly submission are planned before the production run, including three pre-prototypes, one prototype and one pre-production submission. The pre-prototypes are completed before the start of MREFC.
- The COLUTAv3 chip includes two circuit variants (DRE and MDAC), which will be investigated for performance and compatibility with the input signal format.
- A key component of the high-speed radiation tolerant optical link, lpGBT ASIC, passed all functionality tests, but needs additional work to meet radiation requirements.
- Analog Testboard has been used to validate the full readout chain with a small number of pre-prototype PA/shaper and ADC ASICs. The FEB2 prototype board, Slice Testboard, will instrument up to 32 channels of FE channels, i.e. ¼ scale of the final FEB board.

- The LAr BE electronics consists of Liquid Argon Signal Processor (LASP) boards and "Smart" Rear Transition Modules (sRTMs). Specifications for the sRTMs (NSF scope) have been defined during the R&D period and firmware development has started.

Comments:

- The team has clearly demonstrated the positive science impact of the LAr system upgrade with specific examples. The design choices and specifications are rooted in physics goals such as the dynamic range of the FEB board needed for precision Higgs' mass measurements.

- Interfaces between the NSF and DOE scopes are clearly defined, though the dependence on the preamp/shaper ASIC (DOE scope) continues to carry risks for the FEB2 deliverables and should be closely monitored.

- The number of development and prototype design cycles of calorimeter system ASICs is well motivated.

- The staged approach for developing the ADC ASIC has provided confidence and validation to the designs. Issues occurring in COLUVAv1 and v2 of the pre-prototypes have been identified and addressed in the v3 design. The radiation test for the COLUVAv3 chip should be scheduled as early as feasible so the test results could provide input into the prototype design.

- There has been excellent progress on the custom ADC development evident in the performance of COLUTAv2 chip. COLUTAv3 is a substantial fully functional evolution from COLUTAv2. The project is well advised to retain the COTS risk mitigation strategy through to comprehensive radiation hardness studies of COLUTAv3.

- The project has studied system strategies to fall-back from the nominal dual 14-bit range design to a single range design. The project is well advised to retain and develop as necessary this fall-back option in order to preserve descope options. Ideally, the implementation should allow for a staged return to the dual-range system and should be compatible with either the custom or COTS ADC choice.

- It is expected that the FEB2 voltage regulators will be selected from candidate parts that have already undergone radiation qualification. The selection is needed before completion of the Slice Testboard design.

Recommendations:

None.

a. Project documentation describes how the construction-ready design is derived from the flow-down of science goals to science requirements then on to technical performance

specifications and requirements. The documentation is in a format that enables traceability, is clearly explained, and is aggregated into a dedicated section of the PEP.

Traceability from science requirements to international ATLAS specifications and then to NSF-scope requirements and specifications is clear and well done. While the NSF-scope is not construction ready today (as scheduled activities in the pre-construction phase remain), there is a clear path to construction readiness on the timescale of the international ATLAS Production Readiness review and the Panel is confident the project will be ready for construction start.

b. All detector functions and requirements are reflected in the Performance Measurement Baseline.

The international ATLAS specifications establish a clear Performance Measurement Baseline which has been well translated to NSF-scope requirements and specifications.

c. Scope documentation includes modelling of impacts to science goals resulting from detector over- and under-performance.

The MREFC project team has done an exemplary job in modelling the impact of detector performance on science goals.

d. The project has identified and assessed the impacts on the project resulting from any changes to scope requirements since the Preliminary Design Review (PDR).

The project scope requirements are essentially unchanged since the PDR.

e. Design specifications and drawings are complete and of high quality. Review any changes in technology since the PDR.

Design specifications and traceability are high quality. While construction drawings are not available, drawings and associated documentation are appropriate for this stage of pre-construction.

f. Specialized technologies enabling the scope fabrication are sufficiently mature to begin construction.

Specialized technologies are sufficiently mature to begin the MREFC phase.

g. Technical scope elements of the performance baseline remain consistent with what was approved for advancement to Final Design stage following PDR.

The performance baseline codified in the ATLAS specifications relevant for the NSF scope has been stable since the PDR.

h. Work packages and Control Account Managers are assigned for construction work anticipated to begin in FY 2020.

Yes.

Tile Cal

The Tile Cal team has developed a design that is mature and will be ready for construction by the ATLAS Production Readiness Review. The team has strengthened engineering oversight which has substantially benefited the overall system design. The design is dependent on CERN deliverables, notably the ELMB2 control board.

Comments:

- The Tile Calorimetry design is mature and has benefited from a well thought out program of prototypes and beam tests.
- The "Main Board" (6.5.1) design is particularly mature and is construction ready.
- The Low Voltage Power Supply (LVPS) control card "ELMB2" motherboard (6.5.3) scope has been substantially simplified with CERN's recent decision to postpone development of the ELMB++ controller in favor of evolving the existing ELMB controller to ELMB2. The reduced scope is now relatively modest and could reasonably be combined with the LVPS (6.5.4) scope.
- The power distribution system has been simplified since the NSF PDR and is considerably more robust through point-of-load regulation on the Main Board. Radiation qualification of components is underway. Radiation tolerance of the ELMB2 control board and LVPS components is potentially an issue.

Recommendations:

- The Project teams should clarify and clearly document the requirements for LVPS radiation tolerance and the strategy for verifying compliance. Mitigation strategies in the case of marginal tolerance should be identified and clearly documented.

a. **Project documentation describes how the construction-ready design is derived from the flow-down of science goals to science requirements then on to technical performance specifications and requirements. The documentation is in a format that enables traceability, is clearly explained, and is aggregated into a dedicated section of the PEP.**

   Traceability from science requirements to international ATLAS specifications and then to NSF-scope requirements and specifications is clear and well done.

b. **All detector functions and requirements are reflected in the Performance Measurement Baseline.**

   The international ATLAS specifications establish a clear Performance Measurement Baseline which has been well translated to NSF-scope requirements and specifications.

c. **Scope documentation includes modelling of impacts to science goals resulting from detector over- and under-performance.**

   The MREFC project team has done an exemplary job in modelling the impact of detector performance on science goals.

d. **The project has identified and assessed the impacts on the project resulting from any changes to scope requirements since the Preliminary Design Review (PDR).**

   The project scope requirements are essentially unchanged since the PDR.

e. **Design specifications and drawings are complete and of high quality. Review any changes in technology since the PDR.**

   Design specifications and traceability are high quality. While construction drawings are not available, drawings and associated documentation are appropriate for this stage of pre-construction.

f. **Specialized technologies enabling the scope fabrication are sufficiently mature to begin construction.**

   Specialized technologies are sufficiently mature to begin the final design phase. Final radiation qualification of some sub-system components (e.g. ELMB2) remains to be done.

g. **Technical scope elements of the performance baseline remain consistent with what was approved for advancement to Final Design stage following PDR.**

   The performance baseline codified in the ATLAS specifications relevant for the NSF scope has been stable since the PDR.

h. **Work packages and Control Account Managers are assigned for construction work anticipated to begin in FY 2020.**

   Yes.

Muon

The main science driver of the HL muon system upgrade is the high-pT physics, and Higgs physics in particular. Physics drivers for each element of the upgrade are well justified with detailed flow-down studies. There has been substantial R&D progress and few tasks remain before MREFC. Most WBS deliverables have passed their ATLAS PDR. The team has an excellent track record with many decades of experience in the design and test of gas detectors, precision timing electronics, and online data processing.

Findings:

- sMDT has made excellent progress setting up the U.S. chamber assembly facility and bringing it to the production-ready state. The first prototype sMDT chamber (BMG type, 432 tubes) has been constructed and is used for cosmic ray measurements. The sMDT chamber Module 0 demonstration is delayed due to material arrival. Nevertheless, the project has adequate float to meet its schedule objectives.

- The TDC prototype v1 is functionally complete. It has passed pre-radiation performance requirements, significantly exceeding some of them. The TDC v2 will be submitted for fabrication in September 2019 and is expected to achieve all requirements.

- Chamber Service Module (CSM) v1 successfully passed testing. CSM v2, with the test version of lpGBT chip, will be submitted and tested before April 2020. The second prototype of the CSM will address power, thermal, and mechanical constraints. CSM production-readiness will be defined by the availability of the production version of the lpGBT chip.

- The L0MDT design has significantly matured since PDR and the U.S. role had been clarified. The first partial hardware prototype has been fabricated and is currently under test.

Comments:

- A post-PDR adoption of the Apollo technology for L0MDT trigger results in a streamlined design, fewer on-board FPGA's, and better cooling of the trigger boards. It creates an additional external dependence on the CMS project, however it might also benefit from the board testing by CMS.

- CSM dependence on lpGBT is common for all LHC upgrade projects. The existing version of lpGBT chip satisfies radiation tolerance requirements of the ATLAS muon upgrade.

- The current status of the muon system meets the technical criteria for NSF FDR, and the project team needs to be commended for bringing it to this stage.

a. Project documentation describes how the construction-ready design is derived from the flow-down of science goals to science requirements then on to technical performance specifications and requirements. The documentation is in a format that enables traceability, is clearly explained, and is aggregated into a dedicated section of the PEP.

The flow-down of the science goals to science requirements and, through them, to technical specifications and requirements to the muon system upgrade is clearly explained. Path to construction-ready design by the time of the project start is well-defined

b. All detector functions and requirements are reflected in the Performance Measurement Baseline.

Performance Measurement Baseline establishes well-defined detector requirements and specifications.

c. **Scope documentation includes modelling of impacts to science goals resulting from detector over- and under-performance.**

   Project presented extensive and rigorous simulation studies detailing the impact of the detector performance on science goals.

d. **The project has identified and assessed the impacts on the project resulting from any changes to scope requirements since the Preliminary Design Review (PDR).**

   A detailed study of the impacts of changes to scope requirements on the scientific program of the experiment has been performed by the project.

e. **Design specifications and drawings are complete and of high quality. Review any changes in technology since the PDR.**

   Post-PDR technology changes are fairly small: the project adopted a common with CMS Apollo trigger board for L0MDT trigger.

f. **Specialized technologies enabling the scope fabrication are sufficiently mature to begin construction.**

   Technologies specific for the project are at a maturity level allowing the project to begin construction.

g. **Technical scope elements of the performance baseline remain consistent with what was approved for advancement to Final Design stage following PDR.**

   Elements of the project technical scope are consistent with what has been approved for advancement to Final Design stage.

h. **Work packages and Control Account Managers are assigned for construction work anticipated to begin in FY 2020.**

   CAMs and work packages are assigned.

QA/QC

The project is paying adequate attention to quality assurance practice. QA/QC documents are in place for all WBS deliverables. Most are well-formulated, but they differ in degree of detail. Going forward, it would be useful to update these documents to include additional criteria, including:

- version control process for software and firmware
- criteria for simulation sign-off
- test stand and test suite description
- description of radiation qualification, if any
- description of any accelerated ageing, burn-in, or other stress tests

- repair/rework procedures
- list of performance parameters and interfaces tested with pass/fail criteria (no TBDs), each referenced back to the appropriate specification document
- description of QC documentation, including database design

The project may also wish to revise the HL-LHC Quality Assurance Plan (HL-LHC-doc-5-v7) by making it more concise, more closely aligned to actual subsystem practice, and less DOE-centric.

Systems Engineering

Findings:

- The project established and exercises basic configuration management. As evidenced by the Baseline Change Proposal Request Log (docDB# 626), formal change control process is observed since September 2018. The process is defined in the Configuration Management Plan (docDB# 7). Controlled US Configuration Items are captured in the US ATLAS HL-LHC Central Documentation archive (docDB) maintained by Brookhaven National Laboratory. Overall ATLAS documentation archive is maintained by International ATLAS.
- Project systems engineering procedures are established in the Systems Engineering Management Plan (docDB# 266). Specifications and design are assessed and approved through the International ATLAS review process: Specification Validation Review (A-SVR), Preliminary Design Review (A-PDR), Final Design Review (A-FDR), and Production Readiness Review (A-PRR), conducted at each phase of the project (prototype, pre-production, production) allowing the start of the next phase.
- In general, Front End (on-detector) components are carried through prototyping by NSF Pre-MREFC support, while Back End (off-detector) components are approaching the end of the design phase. 7 of the 14 components in the NSF scope have already approved specifications, i.e. went through the Specification Validation Review.
- The Scientific Objectives and Scientific Requirements are clearly explained in the Project Execution Plan (docDB# 78). L-2 and L-3 subsystem requirements flow down from “Physics Goals” to “Object Performance” to “Technical Specifications” is summarized in the US ATLAS HL-LHC Science Flowdown document (docDB# 269), referencing a number of ATLAS documents and publications.
- The fundamental interface for the project is captured in an International ATLAS document: “ATLAS Trigger & DAQ: Interfaces with Detector Front End Systems – Requirement Document for HL-LHC” (ATL-D-ES-0051). The document is under formal ATLAS change control, approved in May, 2018. International Atlas has established and observes rigorous specification regime, as evidenced by this document.
- Each L-3 subsystem presented initial QA/QC plans and verification methods, although in general there are no overall standards imposed by International ATLAS. The key requirements for each L-2 subsystem are well understood and on the panel’s request compliance assessments were presented for these key specification items. While compliance with most of the key specifications have been established by prototype or demonstrator tests, in some cases compliance expectations are based on engineering estimates and analogies.

Comment:

- The systems engineering products and procedures of the US ATLAS project are mature to support the MREFC-funded construction starting in April 2020. Systems engineering is carried out in close collaboration with the International ATLAS project, ensuring that specifications, interfaces, reviews and the technical decision-making processes are consistent with overall ATLAS objectives.

Recommendation:

The project should further develop the customary verification and compliance matrices to track predicted performance (several examples were examined during the review). Compliance expectations are management tools precipitating risks and in turn mitigation actions. Verification matrices and plans ensure a consistent framework and methodology for system, subsystem, and component verification.

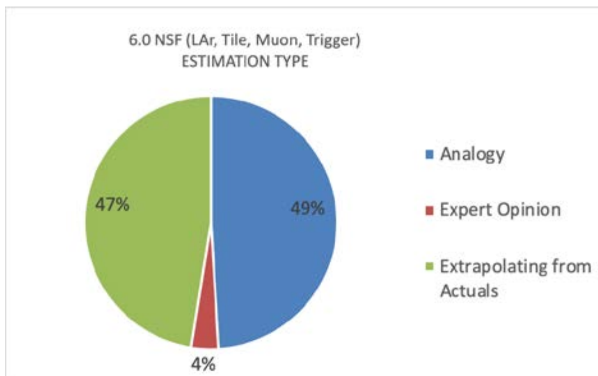
Project Cost/Schedule/Risk Review

1. ***Project Budget***
   a. ***The complete scope of work to be funded by NSF with MREFC funds is captured in a detailed WBS format, accompanied by a WBS dictionary defining the scope of all entries.***

      FINDING: The Panel finds that complete Atlas NSF scope is captured in a detailed WBS format and is accompanied by a WBS dictionary which defines the scope of all entries.

   b. ***A significant proportion of the budget is based on externally provided information such as current vendor estimates or quotes, publicly available supplier prices, and the like, especially for FY 2020 and FY 2021 budgets.***

      The type of estimate is illustrated in the following chart (provided by the project)



      The graph illustrates that 96% are either extrapolated from actuals or Analogy which is a good basis. The ATLAS team's presentations stated that vendor quotes have been updated to be less than a year old. The Panel did a drill down to verify that the BOE estimates are consistent with the P6/Cobra and reporting system.

      Conclusion: The Panel found minor issues (see drilldown footnotes below) but for the vast majority of cases the estimates were well supported.

   c. ***The bottom-up cost estimate is well-supported, assumptions are reasonable, and all costs (including estimated costs for project management staff, common costs, COLA, and teaching buyouts) are incorporated into the resource-loaded schedule.***

      FINDING: The sampled bottom-up cost estimates were well supported and the assumptions were generally reasonable. All costs sampled were incorporated into the resource-load schedule.

      COMMENT: The procurement plan for the WBS 6.8.2 HTT purchases anticipates the purchase, manufacture and receipt of $5.6M of hardware in a single year. The Project recognizes this as a risk and plans to mitigate it by working with the ultimate supplier(s).

      RECOMMENDATION: The Project should contact potential suppliers prior to the start of the MREFC phase to verify that its assumptions regarding throughput are reasonable.

d. ***Methodologies for estimating equipment and material quantities and labor hours are reasonable. Any adjustments from historical data are valid.***

FINDING: The sampled equipment quantities and labor hours were reasonable and historical data was recent and valid (see project drilldown).

e. ***The NSF funding and obligation profiles from NSF to the project are consistent with risk-adjusted project obligation/expenditure plan (i.e. the risk-adjusted budget profile includes the contingency budget profile based on forecast risks and when they might be realized).***

FINDING: The NSF funding plan appears to be adequate to cover the planned annual risk-adjusted costs estimated by the Project.

COMMENT: The Project's 'best estimate' anticipates the expenditure of all of its contingency. In addition, the Project has prepared a reasonable plan which identifies about 15% of the budgeted cost (descopes) for removal subject to negotiations with CERN.

2. ***Project Schedule***

a. ***The high-level construction schedule includes critical path and near critical path milestones, the estimated project end date, and schedule contingency.***

Development of the schedule is consistent with the best practices in the Government Accountability Office publication GAO-16-89G dated December 2015, "Schedule Assessment Guide: Best Practices for Project Schedules." (Best practices 9 and 10, addressing schedule updates and maintenance, are not applicable to this early stage.) A complete RLS schedule was presented to the Panel for each WBS L2 item. The presentations and team's responses to questions shows evidence of proper vetting at this stage.

b. ***Task durations and schedule estimates are reasonable and based on the technical requirements and past experiences, including the schedule needs for testing new technologies.***

FINDING (a & b): The Project has prepared a critical path for the overall project. Durations for individual tasks are based on best case scenarios and individual tasks do not generally contain schedule slack. Generally, all float is aggregated at the highest WBS level.

COMMENT: Given that all float is aggregated at a high WBS level, the use of float will be a draw on contingency. The project has appropriate defined processes for this contingency use.

c. ***The performance baseline schedule includes the complete scope of work including quality control and assurance, safety, and acceptance testing. The activities and/or milestones associated with scientific labor are discrete and can be measured for performance.***

d. ***The project control system includes means for monitoring the contributions from scientific labor to the accomplishment of project milestones. The project has a feasible method for managing, tracking, and reporting the work accomplished by those contributing labor.***

FINDING (c & d): The Project baseline schedule (including float) contains all effort required for completion of the NSF's scope. The Project is capable of managing, tracking and reporting all work accomplished.

e. ***Project milestone granularity is appropriate to inform project management decisions***

Comment: We concur

3. ***Project management and the Project Execution Plan, including governance of the project, working with interagency and international partners, and subaward management.***
   a. ***The Project Execution Plan adheres to the format described in Table 3.4.1-1 of NSF's Major Facilities Guide[1].***

   Comment: We concur.

   b. ***The project management plan describes governance of the project, configuration control plans, Earned Value Management System (EVMS), risk management, QA, Safety, and plans for reporting technical and financial status, managing sub-recipients and working with interagency and international partners. The project management plan also includes:***
      i. ***A fully implemented Project Management Control System (PMCS), including a final version of the resource-loaded schedule and mechanisms for the project to generate monthly status reports and use them as a management tool. Path dependencies, schedule float, and critical path are defined within the PMCS.***
      ii. ***NSF reporting plans and plans for oversight of subawardee performance. PMCS tools are ready for technical and financial status report, risk management.***
      iii. ***Preparatory PMCS training and EVMS reporting for managers is complete.***

   FINDING: The Project's management plan meets the NSF's criteria stated above. The PMCS incorporates a mature EVMS that has been certified by DOE and is being used for pre-MREFC scope, providing high confidence that performance data will be reliable during project execution. In addition, NSF will independently assess implementation of the certified EVMS.

   c. ***The Project Execution Plan (PEP) documents the number of contributed scientific labor hours (not dollars) and how it is time-phased within each work package's Basis of Estimate (BOE) so that the total effort is explicit and transparent.***

   Comment: We concur.

[1] https://www.nsf.gov/bfa/lfo/docs/Major_Facilities_Guide_2019_Draft_For_Public_Comment_December_2018.pdf

d. ***The PEP documents assumptions about the source of travel funds for construction-related travel for scientific labor.***

Comment: We concur.

e. ***A construction-ready resource-loaded schedule (RLS) has been developed and internally vetted by the project to assure accuracy of inputs.***

Finding: We concur.

f. ***The project has satisfactorily documented interfaces (internal and external of the NSF scope) and has processes in place for controlling interface changes.***

Finding: The Project is fully capable of documenting and controlling both internal and external interfaces.

ATLAS has schedule substantial float (one to two years) prior to current CERN need dates. ATLAS Global Risk ($1.1M – $3.9M cost range) RN-06-10-01-005 also addresses this issue.

g. ***The RLS defines adequate schedule float for delivery and acceptance testing in advance of the "need by" dates of the international construction effort.***

Finding: The Project has ample schedule float in each WBS to accomplish tasks by the need by dates of CERN.

Comment: If the Project were to use its entire float, it may require a reduction in scope to remain within the $75M cap.

h. ***The project has developed and substantiated a risk-adjusted budget (baseline budget by NSF fiscal year, plus estimated annual contingency by NSF fiscal year).***

Finding: The ATLAS total risk-adjusted cost of $75 million includes contingency developed via a Monte Carlo simulation and has an overall confidence level of 77.5% CI which is within the 70-90% range recommended by the NSF Major Facilities Guide.

i. ***There are clear boundaries between Pre-MREFC, MREFC, and post MREFC (installation and commissioning) scope for all project deliverables.***

Finding: In all cases examined, the definition of pre-MREFC and MREFC activities were clearly and separated.

j. ***Performance verification and acceptance test policies for all deliverables are defined and complete. Documentation describes how acceptance tests will verify that deliverables meet design performance specifications and safety requirements.***

   i. ***QA plans and activities are integrated into the RLS.***

ii. QA and radiation exposure policies are applied consistently across the project.

See QA/QC section above.

k. ***There is a vetted safety plan and appropriate safety experts are available to the project to implement and oversee the safety plan****.*

Not reviewed in detail. ESH plans as presented built on institutional plans, and appeared appropriate.

l. Plans and justifications for fabrication of spares within the construction program are defined and well justified.

Finding: During the presentation the ATLAS team estimated spares for the various material and equipment L3 WBS task BOEs. Spares quantities were based on prior experience and the team's expert judgement.

Comment: Given that a significant number of CAMs have direct experience with the prior program the spares estimate appeared sound.

m. Plans and schedules for shipment of deliverables to CERN are credible and appropriately integrated into the RLS.

Finding: Plans and schedules for delivery to CERN were demonstrated.

n. Export licensing requirements (if any) are identified and accommodated within project plans.

Finding: According to the Project, none of the deliverables are subject to ITAR restrictions. Some deliverables apparently fall under EAR-99 commercial export controls, however for export to Switzerland no license is needed.

4. Risk Management Plan (RMP):

a. The RMP addresses project needs. It describes the current understanding of major project risks ("known unknowns") and key challenges/issues, including external partnering. The risk register appears to include all[2] foreseen risks. It includes the description and assessment of the impacts of any changes since PDR. The RMP identifies risks, quantifies impacts, estimates probabilities, describes plans for risk avoidance, and plans for mitigating realized risks.

Finding: ATLAS has a well-developed Risk Management Plan and Risk Register. The Project Office and the CAMs are utilizing the risk management process and they seem well educated in its proper use. External partnering is specifically addressed (Risk RN-06-10-01-005).

[2] This includes dependencies on the external program and anything that can impact the TPC, schedule, or add risk are addressed. Dependencies on the international ATLAS or CMS upgrades programs are documented and foreseen risks

Comment: The Risk Register appears quite comprehensive for this stage of the project and the ATLAS team regularly reviews and adjusts the Risk Register to reflect the latest state of project knowledge.

b. The RMP describes appropriate processes for risk management, including reporting and updating the status of the risk register during construction.

Finding: The ATLAS Risk Management Plan has included the appropriate processes.

Comment: Their association with BNL and their risk processes are a clear strength. The Panel saw reports of both schedule and cost risk status.

c. The RMP documents budget and schedule contingencies, supported by detailed risk analysis and using credible methodology, and the documentation is aligned and presented in a format that follows the WBS baseline budget. Project cost and schedule contingencies are appropriate for the project and its associated risk.

Finding: ATLAS's risk processes and corresponding analysis appears to support the project's contingency. The ATLAS team has used Monte Carlo simulation to assess that the overall contingency budget supported a 77.5% confidence level. This is within the 70-90% recommended range guidance provided by the NSF Large Facilities Manual.

Comment: In addition, ATLAS has found the 77.5% CI is confirmed by historical judgement based on past project's maturity stage.

d. The RMP documents a credible plan to mitigate the impact from a potential 10, 20, or 30% DOE base program descope in any given project year.

Finding: ATLAS Global Risk RN-06-10-01-004 addresses this issue. The risk shows a span of cost impact from $200k to $1M. ATLAS project management estimates that a 10% decrease can be ameliorated by DOE base staff priority shifts with a 30% reduction costing approximately $150k/year for the worst year.

e. Monte Carlo estimation methods address PDR panel concerns about estimation methods. (For example, Budget contingency estimation methods avoid double counting impacts of both risk and uncertainty, have justifications for risk probability distributions, and segregate risks in pre-construction prototyping from MREFC-funded activities and related risks.)

Finding: The ATLAS risk estimation process supports the NSF's no overrun policy. The Panel has found no evidence of double counting.

f. ***The project cost and schedule contingencies have been credibly estimated and are appropriate for the project and its associated risk.***

Finding: The total risk-adjusted cost has a reported 77.5% confidence level.

g. ***Schedule Risk Management:***

   i. The project critical path and schedule float are defined and optimized.

   ii. Formal schedule contingency management is used to manage schedule risk.

Finding: ATLAS has provided critical path schedules for each level L2 item in the NSF scope WBS. The P6-based process that has been developed and managed by the experienced BNL/Columbia team appears sound.

Comment: Contingency management appears sound. For example, uncertainties in external delivery interfaces (CERN) are being addressed by substantial schedule float on activities that are affected by these dates.

h. ***Scope management plan includes the following:***

   i. It identifies a reasonable level of available options (target 10% of the performance baseline) expected to available to the Project Manager mid-to-late in the construction program (when remaining budget contingency may be insufficient).

   ii. It documents scope options, and the motivation for including them, which could be added to the project's baseline scope at a later date if the project encounters favorable risk experience.

(i-ii) Finding: ATLAS processes are documented in their Scope Management Plan. ATLAS has presented potential descope items of $8.4M or 15% of the base costs. Many of these items are available midway in the construction process. Up-scope items sum to $6.3M or 11.4% of the ATLAS base cost.

   iii. ***It includes an assessment of the science impacts resulting from the exercise of options to eliminate or add scope in response to risk***

Finding: The vast majority of downscope and up-scope items are material and equipment based so scientific labor would not apply. The science impacts of the up-scopes/downscopes have been characterized and can be used in decision-making processes as the project evolves.

Footnote 1: Drilldown verifications:

The ATLAS Project team provided or worked through a number of drilldown examples in the following tasks:

WBS	WBS Name	Expense Type	BOE Support Examined
6.8.1	L O Calo Fiber Optic Plant	Procurement	Vendor Quotes
6.8.2	HTT Management	Procurement – BOE to Vender Quotes, P6/Cobra, Performance Reports	Vendor Quotes, P6/Cobra, Performance Reports
6.8.3	Global Trigger Firmware	Labor	P6/Cobra drill down; Analogy
6.4.1	LAr FEE	Procurement	Vendor Quotes
6.4.2	LAr Front End Board (FEB2)	Procurement	Vendor Quotes
6.4.3	LAr Back End Electronics	Procurement	Vendor Quotes
6.5.1	Tile Calorimeter Main Board	Procurement	Vendor Quotes
6.5.3	Tilecal ELMB2	Procurement	Summary, Judgement
6.6.1	sMDT	Procurement	Vendor Quotes as relayed by MPI
6.6.3	Time to Digital Converter (TDC)	Labor: QA/QC on chips	Analogy
6.6.4	Chamber Service Module	Procurement	Vendor Quotes
6.6.5	L0 MDT Trigger Processor	Labor: Engineering	Engineering Buildup

The Panel felt that the drilldowns appeared sound. To confirm the validity of the Project's drilldowns, the Panel preformed a detail check WBS 6.8.2 and 6.8.3 (shown below).

The ATLAS Project Team provided drilldown examples which were reviewed and verified by the Panel. WBS 6.8.2 – HTT Management's (Mel Shochet Level 3 Manager and CAM) drilldown consisted of a large $4,055,418 production board procurement. The Basis of Estimate was compared to the corresponding quotes, P6 Schedule and Cobra entries, and the BNL/Columbia Project offices performance reports. The numbers were de-escalated, and escalated at 3% per year to adjust to the proper time period. The budget numbers were consistent and explicit for the majority of costs. A minor discrepancy of ~$3,000 was due to a shipping cost that was included but was not made explicit in the detailed cost breakout.

For Labor WBS 6.8.3 Global Trigger Firmware (Stephanie Majewski Level 3 Manager and CAM) was chosen. This was a good candidate for drilldown as the task spans eight level four tasks, six Level 4 CAMs, and five different institutions. The drill down focused on Level 4 Task 6.8.3.4 (jet-finding algorithm) version 2 development cycle (1514 hours). The WBS Basis of Estimate was consistent with the corresponding P6 schedule activities. The estimate is based on Analogy (factoring from firmware development in the prior global trigger project). These costs were factored by 1.5 based on the CAMs and technical team's judgement. In addition, the ATLAS team compared the effort with effort for other algorithm deliverables, such as Level 4 tasks 6.8.3.5, 6.8.3.6, and 6.8.3.7. The Panel found the estimating process was sound and utilized multiple estimates to increase accuracy. In addition, the Panel examined the P6/Cobra system calculation of the estimate. The calculation proved to be consistent with both the estimation data and methodology as described.

For Procurement WBS 6.5.3, the BOE lacked the rigor of the other estimates. The board and components costs were given in summary and lacked quote dates and a detailed parts breakdown. While the total cost of this deliverable is small, given its scheduled early delivery, a stronger BOE would be expected.

For Labor WBS 6.6.5, the BOE provides a discussion of labor effort. The basis for the estimated effort seems to vary by institution and there is no summary information that enables traceability to the budget. A traceability matrix showing task, total effort and estimation basis would be helpful.

Education Review

1. **The Education and Outreach plan presents substantive, implementation ready plans for leveraging MREFC funding to promote educational outreach and broader impacts. It is centered on a few crisply defined activities that showcase how NSF's MREFC funding will be leveraged within the context of the broader base experimental particle physics research program at the LHC. It includes plans for assessment of impacts.**

   Findings:
   The Education and Outreach (EPO) plan identifies that the major opportunity for leveraging MREFC funding to promote educational outreach and broader impacts is through the specific project work opportunities for 100 undergraduates and high school students in the activity of the participating institutions. This is an appropriate focus given the MRFEC aspect of this project. The project takes advantage of the US ATLAS HL-LHC project operations as a whole. It effectively uses the work opportunity to develop the academic, technical and career skills of these participants. It provides these participants opportunities to participate in wider project-based communities through interactions with others in online discussions, inclusion in cross-institutional project meetings and mentoring opportunities in science and life skills. The project EPO effort includes a plan for the assessment of educational outreach and broader impacts and has a knowledgeable educational researcher on board to administer the plan.

   Comments/Conclusions: The specific work opportunities for the students are well spelled out at the L2 and the CAM level. But there is less of an overall plan presented that knits these individual institutional efforts into a whole. Overall the outcomes of the EPO plan could be articulated better. This is an amazing opportunity to engage 100 students in work on a major project involving many institutions across the country. Most of these participants will become an important addition to the physics and technical community in the future.

   The recruitment and retention plan depends primarily on the individual existing institutional activities. There is a missed opportunity for the project to develop a network of the EPO provider leaders to support the EPO effort. During the FDR the project agreed to explore this idea and also to add the inclusion of EPO reporting requirements from the level 3 projects through level 2 leaders to the project EPO leader and the project leadership as a whole. This latter addition will provide the mechanism to make sure that the EPO goals are pursued by the project.

   Recommendations:

   a. The Education and Outreach plan and goals need to be more clearly defined and articulated (see 2 below as well)
   b. Implement the proposed creation of a network of the individual EPO leads that meets periodically to provide a cross project (and across field) learning opportunity as well as reinforcement of student participation in the cross project activities.
   c. Implement the proposed inclusion of EPO reporting requirements from the level 3 projects through level 2 leaders to the project EPO leader to provide confidence that the EPO goals will be addressed by the project.

2. **It includes a diversity plan, with an implementation strategy and metrics.**

Findings: The project does not yet provide a clear project level diversity plan with a specific implementation strategy and metrics. There are no baseline or goals established to work from. While the project approach depending on the existing diversity strategies of the individual institutions to carry out this work may be effective, there is no rollup of what this would mean at the project levels.

Comments/Conclusions: The local diversity strategies of the university are well developed in support of general student diversity. Right now the project depends on the individual campus efforts on diversity. For many of the projects, the pool of undergraduate students available for recruitment come from the student body makeup appearing in faculty classes. The question is how can this significant project have a larger impact on diversity of the field as a whole. For example could the unique project employment opportunities of the project also support further recruitment outreach into new communities and for new kinds of students (technicians as well as scientists) beyond the traditional student body.

The lack of an overall project level plan and a set of goals on diversity may limit the potential of this project to affect diversity and inclusion. To develop this plan further it would be helpful for the project team to get further advice from others engaged with Diversity and Inclusion including experienced members of QuarkNet and the US ATLAS Diversity and Inclusion Committee among others. During FDR response the project discussed future efforts to connect with the US ATLAS Diversity and Inclusion Committee and the development of a US ATLAS HL-LHC EPO committee that would be helpful. As mentioned in #2, there is a great opportunity for the project to develop a network of the EPO provider leaders to support a discussion of best practices. During the FDR the project agreed to explore this idea.
.

Recommendations:

a. Develop a plan at the project level that identifies an implementation strategy and metrics that can be reviewed at the next project review.
b. Further discussions with knowledgeable members of the US ATLAS Diversity and Inclusion Committee, QuarkNet, and other diversity and Inclusion specialists to inform and review the plan and periodically review progress.

3. **It may document additional education and outreach opportunities, beyond those with (relatively) assured funding through the MREFC and base programs. Additional activities described could further expand the reach and impact of the MREFC/Education leveraging plan, using additional funds obtained following successful competitive review of additional proposals to NSF (or elsewhere).**

Findings: Additional education and outreach opportunities exist at the individual institutional level that can be leveraged by the ATLAS HL-LHC Upgrade project. The local project staff is well prepared to take advantage of these opportunities. There could be additional funding opportunities for additional EPO work.

Comments/Conclusions: It would be helpful to develop a periodic mechanism to collect these more ad hoc local institutional EPO events at the project level. Given the fact that the public does not understand how major science instrument projects are developed and supported, it would also be useful for the project to develop a common communication path (IE logo set or introductory PowerPoint slides) to provide project and NSF identity.

There is also potential mentioned for additional EPO projects to be developed for funding by NSF and others. It is not clear who will be responsible for driving this opportunity in the project.

Recommendations:

a. The project should identify a mechanism to identify and collect at the project level the local additional EPO activity and also develop a way to commonly identify the connection of these activities publically to NSF and the ATLAS Hl-LHC Upgrade project

b. The project should identify potential partners/collaborators for further EPO work and determine the project point person who will be responsible for identifying additional funding for this EPO work.

Additional Comments

- The Panel greatly appreciated the organization and structure of the presentations and documents for the review, including a very effective web interface.
- We noted that establishment of an Ombudsperson program for US ATLAS (spanning institutions) should be considered.

Summary

- We believe the project will be ready for the scope of activities proposed for MREFC funding by April 2020 – **we unanimously consider this FDR successfully passed**.
- An excellent science case and exemplary flow down to technical and operating requirements were demonstrated.
- The Panel congratulates the project on passing the Final Design Review; it is particular gratifying to several of the Panel members to see the impressive growth of the project through the Conceptual/Preliminary/Final Design Review sequence.

The Panel thanks NSF (Mark Coles, Shannon Scrivner) for logistics support during the review.

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APPENDIX A

Name	Affiliation
Management	
Tony Beasley	NRAO
Cost/Schedule/Risk	
David Goodman	TMT
Wayne Abba	retired – Abba Consulting
Laura Lockledge	NRAO
Blaise Stephanus	Dartmouth
Technical Review	
George Angeli	LSST
Paul O'Connor	BNL
Liang Yang	U of Illinois Urbana/Champagne
Paul Padley	Rice University
Pavel Murat	FNAL
Bob Tschirhart	FNAL
Education/Public Outreach	
Rob Semper	Exploratorium

APPENDIX B

NSF Review of High Luminosity Upgrades to the ATLAS and CMS Detectors

ATLAS: September 11-13, 2019

CMS: September 18-20, 2019

NSF Review of High Luminosity Upgrades to the ATLAS and CMS Detectors

ATLAS: September 11-13, 2019

CMS: September 18-20, 2019

(both reviews to be held at NSF)

NSF requests that the ATLAS and CMS Final Design Review (FDR) panels assess the readiness of the ATLAS and CMS high luminosity upgrade project teams to commence construction. Each panel is asked to advise NSF regarding the extent to which each detector collaboration has met NSF criteria[1] for construction readiness. NSF also requests that the FDR panels assess the merit of plans[2] to leverage MREFC funding to promote education and outreach.

In preparation for the FDR, the ATLAS and CMS collaborations are requested to provide materials documenting how they have satisfied these criteria along with a cross-reference table linking the materials and criteria. The FDR panel will review this documentation in advance to flag areas where the review panel would like to have a fuller discussion during the in-person reviews on Sept 11-13 (ATLAS) or Sept. 18-20 (CMS).

Post-FDR Timeline

Following FDR, NSF anticipates conducting an internal assessment of construction readiness for each detector upgrade. The FDR panel observations and recommendations, as documented in the review panel reports, will be extremely important factors in this internal assessment process. The NSF Director's consideration of whether to recommend undertaking construction is expected to occur in late Fall 2019. NSF approval to start construction, forecast for April 2020, is also dependent on Congressional appropriation of MREFC funds that are requested in the FY 2020 budget and on National Science Board concurrence with the NSF Director's recommendation (planned for February 2020). *Consequently, the overall goals of each FDR review are to ascertain, as of the date of the FDR:*

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[1] These criteria are listed for reference on pp. 4-7 of this document. They are excerpted from the sections of NSF's Large Facilities Manual and Major Facilities Guide dealing with construction readiness criteria, and they also include those recommendations made by the review panels at PDR and pre-FDR reviews.

[2] NSF expectations for an effective education program are listed for reference on p. 8.

- *That each detector collaboration has completed all NSF-mandated pre-construction preparation needed to enable construction to commence in April 2020, and*
- *To advise NSF as to whether implications of remaining development activities and decision points - planned for the interval between FDR and April 1, 2020 - are reasonably bounded within each project's cost, scope, and schedule estimates to support a confident recommendation for construction in April 2020?*

NSF requests the panel to keep in mind these overall goals when responding to the charge questions:

Charge to the review panel:

1. Based upon the panel's examination of the project team's technical preparation and preconstruction planning, is the project team ready to undertake MREFC-funded construction in April 2020?
    - The review panel is requested to support their recommendation by documenting their examination, within each of the project's Level 2 Work Breakdown Structure (WBS) elements, of "drill-downs" into select lower-level WBS areas to review the reasonableness and realism of the methodologies used to estimate the types, kinds and quantities of resources (budget, schedule, labor, materials, scientific labor, budget and schedule contingency) needed to complete the proposed detector upgrades.
    - The panel is asked to advise NSF on whether each of NSF's readiness criteria, as documented in Construction Readiness Criteria items 1-5, have been met.
2. Based upon the FDR panel's assessment of the project team's risk planning, advise NSF of the panel's level of confidence that the project team can complete the proposed scope of work within the budget and schedule requested.
    - Support this recommendation by advising NSF on whether the risk management criteria have been met.
3. Does the project team have a meritorious plan to leverage NSF's MREFC investment in the high luminosity detector upgrade to achieve broader societal impacts, such as:
    - Advancing discovery and understanding while promoting teaching, training, and learning;
    - Broadening participation of under-represented groups;
    - Broadening dissemination to enhance scientific and technological understanding.
    - Support these recommendations by advising NSF on whether the Education and Outreach Criteria have been met.
4. Recommend issues, if any, for special NSF attention during remaining planning activities or during the first year of construction. Advise NSF on the adequacy of plans for financial and technical status reporting, and for oversight of subawardee performance by the awardee.

Review Agenda: Each project will provide plenary overview presentations to the review panel during the first half-day of each review. The afternoon of the first day, all of the second day, and the morning of the third day will consist of two parallel tracks of breakout sessions:

- One track will examine management, cost, schedule, and risk aspects of the construction plans,
- The other track will examine technical plans and plans to leverage the MREFC funded work to benefit education and outreach goals.

Half-day sessions will focus on each of the four Level 2 WBS areas funded by NSF within each detector upgrade effort. ATLAS and CMS will provide the review panel with the specific titles of presentations and their order of presentation. ATLAS and CMS are requested to allow about half of the time in breakouts to be available for Q&A. Executive sessions will precede the plenary presentations and will be held at other times as needed.

The afternoon of the third day will be devoted to initial drafting of the panel's report in executive session. The review panel is requested to provide a high-level summary set of recommendations to NSF and the project at the conclusion of each review.

NSF Construction Readiness Criteria:

1. **Completion of design and development phase:**
    a. The project has achieved the necessary level of technical preparation and readiness to begin construction.
    b. The project's scientific and technical contributors are credibly expected to accomplish the proposed work scope within the requested budget and schedule duration.
    c. There is a project management team in place that has the capacity and capability (number of personnel, skill set, effectiveness, quality, organizational structure, division of roles/responsibilities, and processes for assigning work) to initiate and effectively manage the project, including appropriate supervision of subawards, beginning in April 2020 and throughout construction.
    d. The project has finalized all necessary commitments and partnerships, including definition of project deliverables, performing organizations, and schedules.
    e. The project has a defined acquisition strategy for purchased items. Designs, specifications and work scope comprising bid packages to industry are in advanced states of maturity and available for NSF review. Bid packages to be released in FY2020 are sufficiently clear and well defined as to be ready for bid.
    f. MOU's and first year SOWs with subawardees are complete. Subaward budgets are well documented, including documentation of overhead rates by subawardee institution.
    g. Tools and technologies needed to construct the project are available. Industrialization of key technologies needed for construction is complete.
    h. Recruitment of key staff and control account managers needed to commence construction of the project is complete.
    i. The Earned Value Management System is ready to be used during construction and there are plans in place for acceptance by NSF prior to construction award.
    j. The project team certifies that:
        i. All pre-construction planning topics, including those listed in Section 3 of the NSF Major Facilities Guide[3] concerning the Project Execution Plan (PEP), are fully complete and determined to be adequate.
        ii. All pre-construction planning topics required by the MFG (section 2.3) are fully complete and adequate.

2. **Project Scope**
    a. Project documentation describes how the construction-ready design is derived from the flow-down of science goals to science requirements then on to technical performance specifications and requirements. The documentation is in a format that enables traceability, is clearly explained, and is aggregated into a dedicated section of the PEP.
    b. All detector functions and requirements are reflected in the Performance Measurement Baseline.
    c. Scope documentation includes modelling of impacts to science goals resulting from detector over- and under-performance.

[3] (See https://www.nsf.gov/bfa/lfo/docs/Major_Facilities_Guide_2019_Draft_For_Public_Comment_December_2018.pdf)

d. The project has identified and assessed the impacts on the project resulting from any changes to scope requirements since the Preliminary Design Review (PDR).
e. Design specifications and drawings are complete and of high quality. Review any changes in technology since the PDR.
f. Specialized technologies enabling the scope fabrication are sufficiently mature to begin construction.
g. Technical scope elements of the performance baseline remain consistent with what was approved for advancement to Final Design stage following PDR.
h. Work packages and Control Account Managers are assigned for construction work anticipated to begin in FY 2020.

3. Project Budget

a. The complete scope of work to be funded by NSF with MREFC funds is captured in a detailed WBS format, accompanied by a WBS dictionary defining the scope of all entries.
b. A significant proportion of the budget is based on externally provided information such as current vendor estimates or quotes, publicly available supplier prices, and the like, especially for FY 2020 and FY 2021 budgets.
c. The bottom-up cost estimate is well-supported, assumptions are reasonable, and all costs (including estimated costs for project management staff, common costs, COLA, and teaching buyouts) are incorporated into the resource-loaded schedule.
d. Methodologies for estimating equipment and material quantities and labor hours are reasonable. Any adjustments from historical data are valid.
e. The NSF funding and obligation profiles from NSF to the project are consistent with risk-adjusted project obligation/expenditure plan (i.e. the risk-adjusted budget profile includes the contingency budget profile based on forecast risks and when they might be realized).

4. Project Schedule

a. The high-level construction schedule includes critical path and near critical path milestones, the estimated project end date, and schedule contingency.
b. Task durations and schedule estimates are reasonable and based on the technical requirements and past experiences, including the schedule needs for testing new technologies.
c. The performance baseline schedule includes the complete scope of work including quality control and assurance, safety, and acceptance testing. The activities and/or milestones associated with scientific labor are discrete and can be measured for performance.
d. The project control system includes means for monitoring the contributions from scientific labor to the accomplishment of project milestones. The project has a feasible method for managing, tracking, and reporting the work accomplished by those contributing labor.
e. Project milestone granularity is appropriate to inform project management decisions.

5. **Project management and the Project Execution Plan, including governance of the project, working with interagency and international partners, and subaward management.**
    a. The Project Execution Plan adheres to the format described in Table 3.4.1-1 of NSF's Major Facilities Guide[4].
    b. The project management plan describes governance of the project, configuration control plans, EVMS, risk management, QA, Safety, and plans for reporting technical and financial status, managing sub-recipients and working with interagency and international partners. The project management plan also includes:
        i. A fully implemented Project Management Control System (PMCS), including a final version of the resource-loaded schedule and mechanisms for the project to generate monthly status reports and use them as a management tool. Path dependencies, schedule float, and critical path are defined within the PMCS.
        ii. NSF reporting plans and plans for oversight of subawardee performance. PMCS tools are ready for technical and financial status report, risk management.
        iii. Preparatory PMCS training and EVMS reporting for managers is complete.
    c. The Project Execution Plan (PEP) documents the number of contributed scientific labor hours (not dollars) and how it is time-phased within each work package's Basis of Estimate (BOE) so that the total effort is explicit and transparent.
    d. The PEP documents assumptions about the source of travel funds for construction-related travel for scientific labor.
    e. A construction-ready resource-loaded schedule (RLS) has been developed and internally vetted by the project to assure accuracy of inputs.
    f. The project has satisfactorily documented interfaces (internal and external of the NSF scope) and has processes in place for controlling interface changes.
    g. The RLS defines adequate schedule float for delivery and acceptance testing in advance of the "need by" dates of the international construction effort.
    h. The project has developed and substantiated a risk-adjusted budget (baseline budget by NSF fiscal year, plus estimated annual contingency by NSF fiscal year).
    i. There are clear boundaries between Pre-MREFC, MREFC, and post MREFC (installation and commissioning) scope for all project deliverables.
    j. Performance verification and acceptance test policies for all deliverables are defined and complete. Documentation describes how acceptance tests will verify that deliverables meet design performance specifications and safety requirements.
        i. QA plans and activities are integrated into the RLS.
        ii. QA and radiation exposure policies are applied consistently across the project.
    k. There is a vetted safety plan and appropriate safety experts are available to the project to implement and oversee the safety plan.
    l. Plans and justifications for fabrication of spares within the construction program are defined and well justified.
    m. Plans and schedules for shipment of deliverables to CERN are credible and appropriately integrated into the RLS.

[4] https://www.nsf.gov/bfa/lfo/docs/Major_Facilities_Guide_2019_Draft_For_Public_Comment_December_2018.pdf

n. Export licensing requirements (if any) are identified and accommodated within project plans.

6. Risk Management Plan (RMP):

a. The RMP addresses project needs. It describes the current understanding of major project risks ("known unknowns") and key challenges/issues, including external partnering. The risk register appears to include all[5] foreseen risks. It includes the description and assessment of the impacts of any changes since PDR. The RMP identifies risks, quantifies impacts, estimates probabilities, describes plans for risk avoidance, and plans for mitigating realized risks.

b. The RMP describes appropriate processes for risk management, including reporting and updating the status of the risk register during construction.

c. The RMP documents budget and schedule contingencies, supported by detailed risk analysis and using credible methodology, and the documentation is aligned and presented in a format that follows the WBS baseline budget. Project cost and schedule contingencies are appropriate for the project and its associated risk.

d. The RMP documents a credible plan to mitigate the impact from a potential 10, 20, or 30% DOE base program descope in any given project year.

e. Monte Carlo estimation methods address PDR panel concerns about estimation methods. (For example, Budget contingency estimation methods avoid double counting impacts of both risk and uncertainty, have justifications for risk probability distributions, and segregate risks in pre-construction prototyping from MREFC-funded activities and related risks.)

f. The project cost and schedule contingencies have been credibly estimated and are appropriate for the project and its associated risk.

g. Schedule Risk Management:

i. The project critical path and schedule float are defined and optimized.

ii. Formal schedule contingency management is used to manage schedule risk.

h. Scope management plan includes the following:

i. It identifies a reasonable level of available options (target 10% of the performance baseline) expected to available to the Project Manager mid-to-late in the construction program (when remaining budget contingency may be insufficient).

ii. It documents scope options, and the motivation for including them, which could be added to the project's baseline scope at a later date if the project encounters favorable risk experience.

iii. It includes an assessment of the science impacts resulting from the exercise of options to eliminate or add scope in response to risk.

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[5] This includes dependencies on the external program and anything that can impact the TPC, schedule, or add risk are addressed. Dependencies on the international ATLAS or CMS upgrades programs are documented and foreseen risks are covered in the risk-adjusted TPC. Financial exposure of the NSF funded program to uncertainties in external dependencies are bounded.

7. Education and Outreach:

a. The Education and Outreach plan presents substantive, implementation ready plans for leveraging MREFC funding to promote educational outreach and broader impacts. It is centered on a few crisply defined activities that showcase how NSF's MREFC funding will be leveraged within the context of the broader base experimental particle physics research program at the LHC. It includes plans for assessment of impacts.
b. It includes a diversity plan, with an implementation strategy and metrics.
c. It may document additional education and outreach opportunities, beyond those with (relatively) assured funding through the MREFC and base programs. Additional activities described could further expand the reach and impact of the MREFC/Education leveraging plan, using additional funds obtained following successful competitive review of additional proposals to NSF (or elsewhere).